



International Conference on Advances in Computational Modeling and Simulation

Dynamic Simulation on a Broken Test of Conductors

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Abstract

Dynamic simulation on the broken conductors for an experimental line section under different load cases was carried out. A finite element model of three span conductors was established in the general software ANSYS. The broken load case can be realized by the birth-death element method in ANSYS. The damping coefficients by the experimental identification were applied to the FEA model. Effect of the damping property of the conductors was considered by the Rayleigh damping method. Dynamic responses of the tensions of the conductors were obtained. Both the residual static tensions and the first peak tensions by the numerical simulations were well agreed with the experimental values. The impact effect is more significant for the location nearer to the broken point. The dynamic impact factors decrease with the increasing of the ice thickness, and the impact factors of conductors without accreted ice are much higher than those of conductors with accreted ice.

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Keywords: Conductors; Broken analysis; Damping coefficient; Tension; Impact factor

1. Introduction

Unbalanced tension is one of the most important controlling loads for the design of transmission towers in cold regions. Unbalanced tensions can be caused in some cases, including non-uniform accreted ice, broken wires, ice shedding and galloping, etc. Broken of conductors is a common phenomenon for transmission lines in heavy icing area. Transient tension of conductors will vary significantly from broken conductors. The cross arm or the tower body will be damaged under the impact of the broken conductors.

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To ensure the safety of the transmission towers in heavy icing area, dynamic responses of the broken conductors should be studied.

In recent years, some numerical and experimental researches on the broken conductors have been carried out in many countries [1-4]. The numerical studies are mainly accomplished by two methods. The first is the static calculating program based on the equilibrium conductor length theory, and the impact effect can't be considered in this method. The second is the dynamic analysis by implicit or explicit method, the dynamic responses from the broken conductors can be calculated. Some simulating and prototype tests for broken conductors have been carried out. The broken tests of conductors and insulators were completed in the Wisconsin tests line by Alian H. Peyrot et al [5]. The longitudinal loads and the effect on the transmission line were studied. John D. Mozer et al [6] carried out a simulating broken test of a three span conductor- ground wire-steel pole system. The broken tensions of the conductors and the ground wires as well as the strains of the steel poles were measured, and the impact factors of the support structures from broken wires were determined.

After the serious ice disaster in South China in 2008, in order to ensure the anti-bending and anti-torsion capacity of transmission towers, the Technical Code for Designing of Overhead Transmission Line in Medium & Heavy Icing Area [7] was revised, and the icing rates were regulated for the calculation of broken tensions. In the past researches, the effect of the accreted ice was almost not considered in the broken analysis and experiments. Furthermore, the damping coefficients of the conductors were not measured in the experiments and an approximate value was assumed in the dynamic analysis.

In this paper, the FEA model of a three continuous span transmission line section was established. The damping coefficients by the experimental identification were applied to the FEA model. The damping coefficients of the line section for different breaking cases were considered by Rayleigh damping. For different types of conductors and ice thickness, conductors broken analysis were carried out. Under different broken cases, time histories of the tensions for the unbroken conductors were calculated. Both the residual static tensions and the first peak tensions by the numerical simulations were calculated and compared with the experimental values. The dynamic impact factors of the conductor tensions were determined.

2. Experimental investigation

The broken tests were carried out at the UHV transmission tower test station of China Electric Power Research Institute. The arrangement of the test section is presented in Figure 1. The span lengths of the three spans are 95m, 100m and 95m in turn.

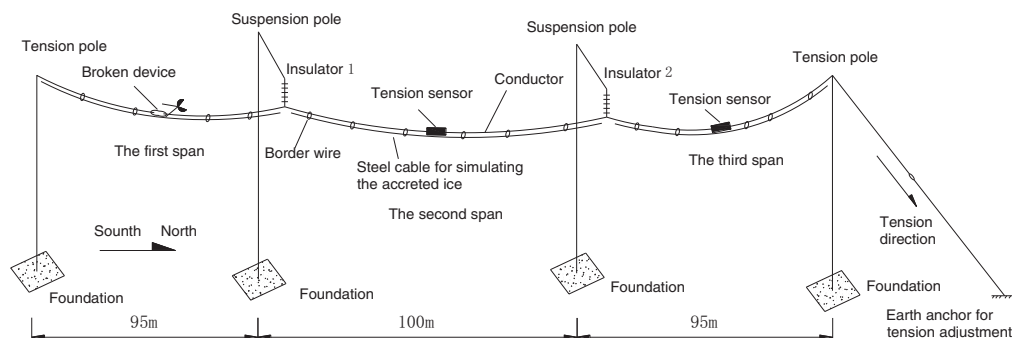


Figure 1. Prototype model of four poles and three span conductors

The broken device was set in the middle of the first span. The tension sensors were installed at the middle of the second span and the third span. The bundle number of the conductor is single. The accreted ice was simulated by steel cables with the equivalent mass. When the conductor of the first span is broken, time histories of the tensions and transverse displacements at the second and the third span conductors were measured. The type of the conductor is JL/GIA 240/30. Mechanical parameters of the conductor are listed in Table 1. The rated tension of the insulator is 7 ton. The structural length of the insulator is 1.7m. Three test cases were completed in this experimental study.

The case description is listed in Table 2. The initial tension of the conductors can be obtained from the tension sensors. The sag at the middle of the second span was measured by a total station. The initial tension and sag should agree with the theoretical relationship. The accuracy of the measured results can be verified by the theoretical relationship. According to the decay method of free vibration, the damping coefficients of the conductor-pole system can be determined from the time histories of the transverse displacements. The damping coefficient for A1, A2 and A3 case is 0.011, 0.015 and 0.036 respectively.

Table 1. Mechanical parameters of the conductor

Section Area(mm ²)	Elastic modulus(GPa)	Expansion coefficient	Maximum working tension(kN)
275.96	73.0	1.96×10 ⁻⁵	30.08

Table 2. Numbers and illustration for the experimental cases

Number	Insulator length(m)	Conductor type	Initial tension(kN)	Ice thickness(mm)
A1	1.70	JL/GIA 240/30	10.5	0
A2	1.70	JL/GIA 240/30	19.2	20
A3	1.70	JL/GIA 240/30	25.2	30

3. FEA model

The FEA model of the test section of three span conductors is presented in Figure 2. Suspension strings are pinned to the cross arms by U type ring, and suspension strings can freely rotate around the longitudinal direction and the transversal direction of transmission lines. The real behavior of the suspension strings is more like a chain of rigid links. So the suspension strings were modeled with LINK8 bar element. The conductors were simulated by LINK10 cable element. The damping effect can be considered by Rayleigh damping coefficient in ANSYS. The damping ratios are valued according to identification results in Section 2.

Firstly, modal analysis of the conductor-insulator system was completed by Block Lanczos method. The first order and the second order natural frequency were obtained. So the Rayleigh damping ratios can be calculated for the broken analysis. Secondly, rupture of the conductor can be realized by birth-death element method in ANSYS by EKILL command. Stiffness of the broken conductor element was changed to be a near zero value in a very short time. The solving process continues 20s. Lastly, dynamic tension forces and the dynamic impact factors of the conductors were analyzed.

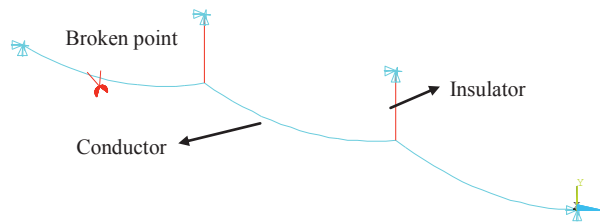


Figure 2. FEA model of a three continuous span conductors

4. FEA results

4.1. Broken tensions

Comparison of the time histories of the tensions under A2 test case is presented in Figure 3. Before the conductor occurs broken, it is in an equilibrium state with the self weight and the initial tension. Immediately at the break time the conductor tension drops to a near zero level and stays at that value for 0.1 to 0.2 seconds. This is followed by the first peak due to the recoil of the tension in the conductors. This peak due to the strain energy occurs only once. A second major peak value follows which occurs at a time interval. After about 15 seconds, the tension reaches a steady value for the effect of the damping properties of conductors. Peak values of the tensions in the second span and the third span conductors are shown in Table 3. It can be seen that the first peak value and the residual static value of the broken tensions by FEA analysis are approximate to the experimental values. The maximum error percent is 12.9% for A3 case. For the difference of the model damping with the real line section, the second peak value of the broken tensions has a relatively big difference with the experimental value.

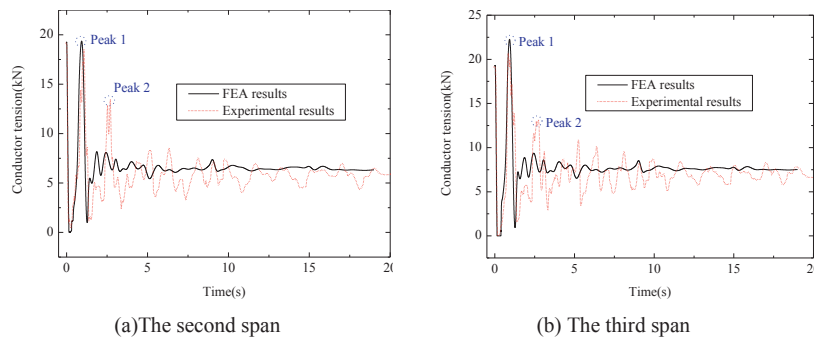


Figure 3. Time histories of the tensions for A2 case

Table 3. Peak values of the experimental tensions

Number	The second span			The third span		
	Peak 1(kN)	Peak 2(kN)	Residual static tension(kN)	Peak 1(kN)	Peak 2(kN)	Residual static tension(kN)
A1	8.97/8.23	5.01/3.38	1.90 /1.85	9.19/9.34	5.24/3.85	2.20 /2.20
A2	18.50/19.38	13.41/8.19	6.20 /6.33	20.72/22.28	13.11/8.89	7.43 /7.52

A3	20.36/22.99	14.97/10.92	9.88/10.03	25.98/26.08	17.91/12.52	12.20 /11.86
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Note: the value before '/' is the experimental value and the value behind '/' is the FEA value.

4.2. Dynamic impact factors

The ratio of the residual static tension to the peak tension after the conductor breaking is defined as the dynamic impact factor, which is expressed by IF as Equation (1). Where T_p and T_r are the peak tension and the residual static tension respectively. The dynamic impact factors of conductor tensions for different cases are listed in Table 4. It can be seen that the impact factor of the second span conductor is higher than that of the third span conductor. The impact effect is more significant for the location nearer to the breaking point. The dynamic impact factors decrease with the increasing of the ice thickness, and the impact factors of conductors without accreted ice are much higher than those of conductors with accreted ice. The impact factor of the A1 case is 1.94 times by the value of the A3 case.

$$IF = \frac{T_p}{T_r} \quad (1)$$

Table 4 Dynamic impact factors

Number	The second span		The third span	
	IF for the first peak tension	IF for the second peak tension	IF for the first peak tension	IF for the second peak tension
A1	4.45	1.83	4.25	1.75
A2	3.06	1.29	2.96	1.18
A3	2.29	1.09	2.20	1.06

5. Conclusions

Dynamic simulation on the broken conductors for an experimental line section under different load cases was carried out. Some main conclusions are as follows.

(1) The first peak value and the residual value of the broken tensions by FEA analysis are approximate to the experimental values. The maximum error percent is 12.9%. For the difference of the model damping with the real line section, the second peak value of the broken tensions has a relatively big difference with the experimental value.

(2) The impact effect is more significant for the location nearer to the breaking point. The dynamic impact factors decrease with the increasing of the ice thickness, and the impact factors of conductors without accreted ice are much higher than those of conductors with accreted ice.

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